SCOUT: A Modular, Multi-Mission Spacecraft Architecture for High Capability Rapid Access to Space

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Abstract. The long lead and cycle times currently associated with development and launch of satellite systems have established a prohibitive environment for both low-cost access and responsive deployment of tactical capability to orbit. With the advent of the RASCAL program — poised to offer launch capability to LEO with less than 24 hours notice — the motivation for a comparable, multi-mission, rapidly configurable microsatellite is clear. The Small, Smart Spacecraft for Observation and Utility Tasks (SCOUT) will enable this capability while summarily addressing the production and logistic challenges essential to its implementation.

SCOUT will challenge the traditional spacecraft systems approach by incorporating a modular "plug-and-play" architecture with a novel approach to assembly, integration, and test activities that spans ground through on-orbit operations. This functionality will enable scaleable multi-mission compatibility, long shelf-life, rapid call-up and field integration for launch, intelligent built-in test capability for rapid initialization on-orbit, and variable batch manufacturability.

Central to this architecture and design philosophy is the notion of "performance" modularity. A modular, plug-and-play system must permit swapping of functional subsystem components while maintaining compatibility with existing ground infrastructure. Similarly, the system must incorporate "assembly-level" modularity to enable rapid system integration in the field for extensibility to multiple mission and applications.

Introduction

Advancements in microsatellite and payload technology now enable small spacecraft (50-100kg) to execute myriad space-based communications, imaging, and sensing activities. Where deployment was previously constrained by launch vehicle availability and long-lead schedules, DARPA's RASCAL (Responsive Access, Small Cargo, and Affordable Launch) program promises to offer the capability to rapidly deploy small payloads into Low Earth Orbit (LEO). This capability, however, begs the question: what candidate systems and architectures will best serve the tactical, responsive space, or time-sensitive opportunities for technology demonstration that are now made available? When one considers the tremendous investment of resources associated with on-orbit systems and this unconstrained operational environment, it is clear that there is a strong need for a highly capable, modular satellite solution to both execute and serve these space missions.

AeroAstro, under a Phase I Small Business Innovative Research (SBIR) contract with DARPA, has developed the Small, Smart, Spacecraft for Observation and Utility Tasks (SCOUT), which will offer:

- *Multi-Mission Compatibility* – The SCOUT architecture will be capable of serving a broad range of missions including, satellite inspection and monitoring (SI&M), near-field situational awareness (NFSA), tactical communications activities, and technology demonstration.

- *High Payload Mass and Power Fractions* – To maximize their effectiveness, the majority of the mass of SCOUT vehicle will be dedicated to payload, with a similar precedent upon high payload power fraction.

- *Long Shelf-Life* – SCOUT vehicles and their component subsystem modules will be storable for several months or years in the field with limited or no maintenance.

- *Rapid Call-Up for Launch* – SCOUT is designed to be readied for use within hours by skilled personnel. To achieve tactical timelines, SCOUT will only require the minimum possible field integration and will have robust, self-diagnostic configuration and built-in test capabilities (BIT).

- *Rapid Initialization on Orbit* – The responsive advantage of SCOUT would be lost if checkout and initialization took 20 to 30 days, as with current small satellites. SCOUT will initialize and be ready to perform its mission within five orbital passes.

- *Manufacturability* – SCOUT vehicles and their subsystem modules will be built in substantially higher quantities than most spacecraft. While 'mass' manufacturing techniques are not necessarily applicable, SCOUT will leverage the manufacturing approaches and procedures commonly utilized by the high-tech and computer industries.

Accordingly, a modular "plug-and-play" system architecture has be devised that will enable deployment of mission-specific vehicles in a manner that is consistent with existing ground infrastructure, yet is transparent to component selection and overall stack configuration. As such, the SCOUT architecture will incorporate a novel approach to assembly-level modularity that spans mechanical and electronics interfaces, as well as software ontologies that will enable robust self-diagnostic and built-in-test capabilities within component modules (i.e., avionics module, propulsion module, various payload modules). Similarly, SCOUT will also include component-level modularity within each assembly (i.e., NiCad vs. Li Ion batteries, field-programmable gate arrays (FPGA) vs. higher capability processors, different radio configurations) to enable new assembly modules to be sent into the field for new missions.

This paper discusses the design of the SCOUT modular, scaleable architecture for rapid-response microsatellite missions. An overview of launch vehicle compatibility will be presented, followed by discussion of the mechanical design, core subsystems, and integration and test process. In order to illustrate how SCOUT might be applied to current microsatellite missions of interest, several sample configurations are also included.

Launch Vehicle Compatibility

One of the goals of SCOUT is to develop a modular microsatellite architecture that is compatible with virtually every launch vehicle in the world inventory. The advantage of this approach is that SCOUT-based spacecraft can be assembled completely independent of the host launch vehicle selection process.

This goal was realized by surveying a wide range of potential launch vehicles and developing a core set of key compatibility parameters that envelope the broadest possible array of requirements. For the purposes of this study, every potential launch vehicle for which compatibility requirements could be easily obtained was examined. A few vehicles were eventually excluded because one or two parameters of their compatibility envelopes were significantly more stringent than the vast majority of potential vehicles. When this process was completed, it was determined that SCOUT could be made compatible with the extensive set of launch vehicles detailed in Table 1.

Table 1: SCOUT Compatible Launch Vehicles

Ariane 4 and 5	Atlas II, III, and V	Delta II, III, and IV
Eurockot	H-IIA	Kosmos
Minotaur	Pegasus	RASCAL
Sealaunch	Space Shuttle (STS)	Taurus

This set of seventeen launch vehicles is biased in favor of US domestic options (11 LV), which must be considered the preference for responsive missions. For missions that can accept manifest on a foreign LV, several non-US vehicles from Europe, Russia, and Japan are included that are also consistent with identified LV requirements. For most of these launch vehicles, it is assumed that SCOUT would use a secondary payload slot.

Based upon the analysis that was performed, the key launch vehicle parameters considered were mass, volume, minimum fundamental frequencies, and quasi-static loads. Note that SCOUT does not use any electrical (i.e., umbilical) connections to the launch vehicle. Table 2 below summarizes these enveloped launch vehicle requirements.

Table 2: Launch Vehicle Requirements

Maximum Space Vehicle Mass	75 kg
Maximum Envelope	
Height	50 cm
Width	44 cm
Depth	44 cm
Minimum Fundamental Frequencies	
Axial	50 Hz
Lateral	40 Hz
Torsional	50 Hz
Maximum Quasi-static Loads	
Axial	13 G
Lateral	2.5 G

Because this is an enveloped set of requirements, it is overly restrictive for many vehicles, notably with respect to Maximum Envelope height. A larger envelope is realized by eliminating certain Launch Vehicles from consideration.

Mechanical & Thermal Design

One key to the utility of the SCOUT architecture with respect to scaleability and extensibility is the functional modularity of the system. Nowhere is this modularity more evident than in the mechanical design of these modules. SCOUT features a uniform field joint that allows any module to mate to any other module. This uniform field joint also provides for electrically mating one module to the next via the "electrical backbone" connector. Additionally, the housing provides an exoskeletal structure that supports launch vehicle mechanical requirements in terms of stiffness and strength without the need for an additional framework. Finally, the exoskeleton provides a thermally conductive path to isothermalize the SCOUT vehicle, both transfering excess heat from "hot" modules to "cool" modules and allowing the outside surface to act as a thermal radiator.

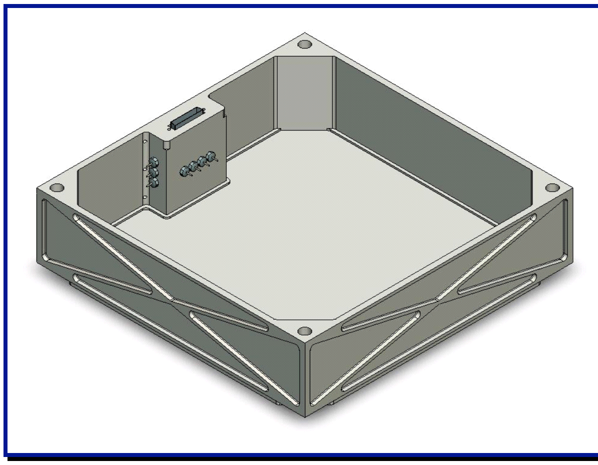

Figure 1: SCOUT Module Top View.

A uniform module cross-section of 25 cm X 25 cm has been selected. The height of the module is adjusted to accommodate different volumes as needed. The height is adjusted in 2 cm increments. The housings are milled from solid aluminum for better thermal and electromagnetic compatibility performance. Each module has a "floor" that serves as the "lid" for the module below. The interface joint is designed so that each module nests into the module below, improving shear strength of the joint and further enhancing the electromagnetic integrity of the housing. The features of this design are illustrated in Figures 1 and 2.

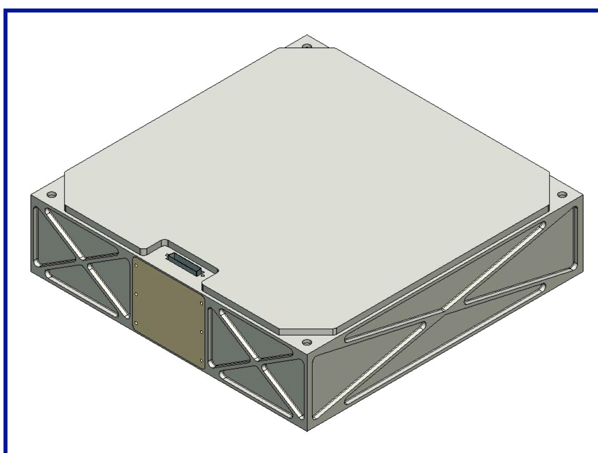

Figure 2: SCOUT Module Bottom View.

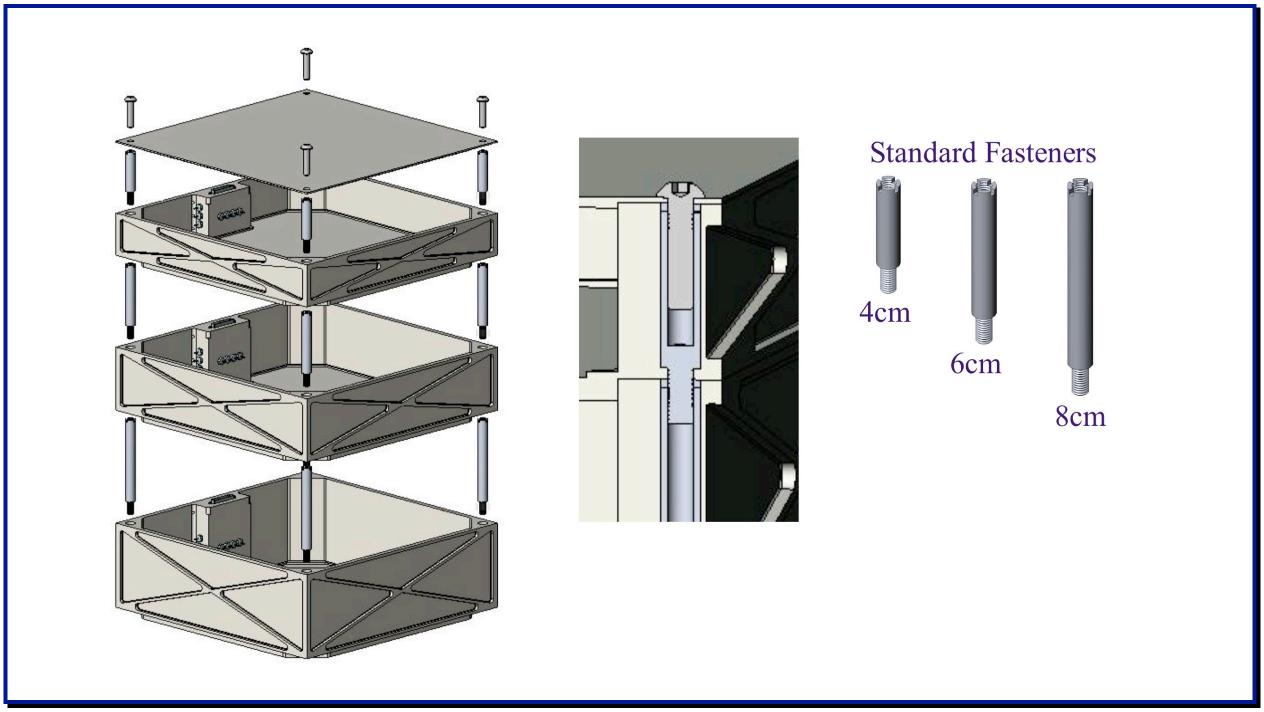

Figure 3: SCOUT Stacking Modules.

The SCOUT vehicle is assembled by stacking the modules vertically until all of the required modules are integrated. As each new module is added to the stack, it is fastened to the unit below it using male/female threaded standoffs shown in Figure 3. These fasteners are manufactured in fixed lengths at standard 2 cm increments to accommodate anticipated SCOUT module heights. The overall height of the entire stack will vary as a function of the modules required to provide the capabilities needed by the spacecraft. If this height is limited to 50 cm or less, the SCOUT vehicle will be compatible with all the Launch Vehicles detailed above. If overall stack height is required to be greater than 50 cm, the number of available LV options will decrease.

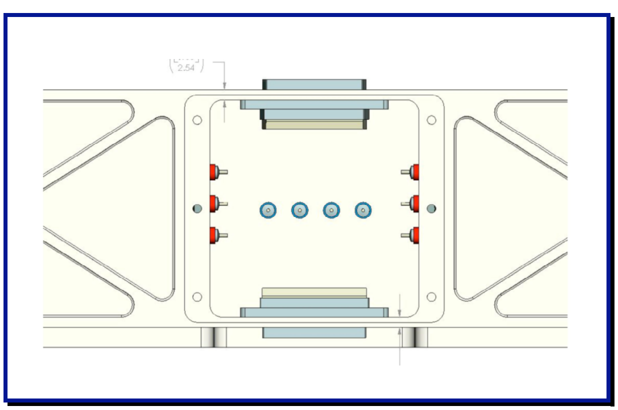

Figure 4: SCOUT Electrical Backbone.

As the modules stack up, the electrical backbone connector on the bottom of each module easily mates to the pass-thru connection on top of the module below. In this fashion, every module has access to the common SCOUT electrical bus that provides unregulated power, low speed data, and high speed data access to each module. The connector also provides a keying reference to help insure that the modules are stacked in a predictable and repeatable fashion. Figure 4 shows the recessed placement of the male connector on the bottom that allows it to mate with the protruding female connector below.

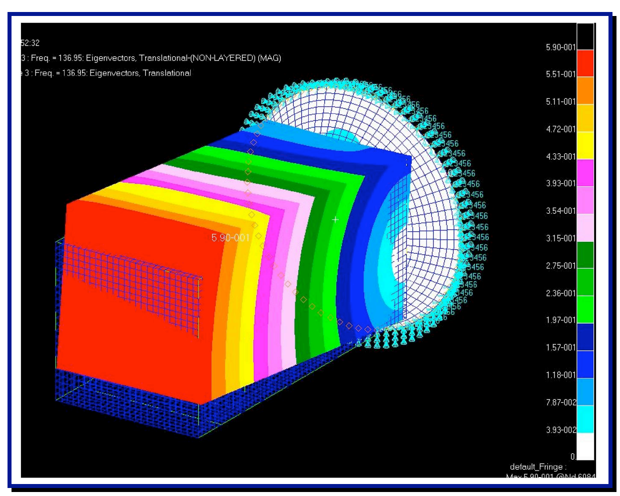

Figure 5: SCOUT Fundamental Modes.

When stacked up in this fashion, this exoskeletal structure provides a robust load-carrying tower. Analyses show that a tower of 50 cm height with a uniformly distributed mass of 75 kg will have a high first fundamental mode. It is observed that the fundamental frequency of the stack is a function of the thickness of the baseplate (see Figure 5). With a thickness of 60 mils (1.5 mm), a fundamental frequency of 69 Hz is achieved. Increasing the baseplate thickness to 200 mils (5 mm) increases the fundamental frequency to 165 Hz.

Command and Data Handling

In order to meet the avionics requirements of the different missions the SCOUT modular architecture could serve, AeroAstro adapted its avionics architecture to provide additional modularity, scalability, and adaptability while retaining a simple design. There are nominally three versions of the SCOUT avionics (Version II detailed in Figure 6), with each of the versions offering successive greater capability. Depending upon the mission and C&DH requirements, this modular avionics architecture can be appropriately sized and configured. As such, SCOUT can be used for a variety of missions ranging from a simple experiment test-bed to complex high resolution imaging. The capabilities of each version are described in Table 3.

Table 3: Avionics Versions

Version I	Version II	Version III
Radiation Tolerant FPGA	Version I plus:	Version II plus:
Power bus monitoring	55 MIPS microcontroller	Up to 1 GB EDAC protected SDRAM
2-MB RAM buffer	64-256 MB EDAC-protected DRAM	
S/C Power-Up and Reset functions	I2C interface for low speed commanding and telemetry	
Power fault detection	IEEE 802.3 for high bandwidth data	
Micro-Instruction: for low level control of the SCOUT	RS-232 interface for software dev and debugging	
Watch-dog timers	uC/OS Operating System	
Command and Telemetry handler		

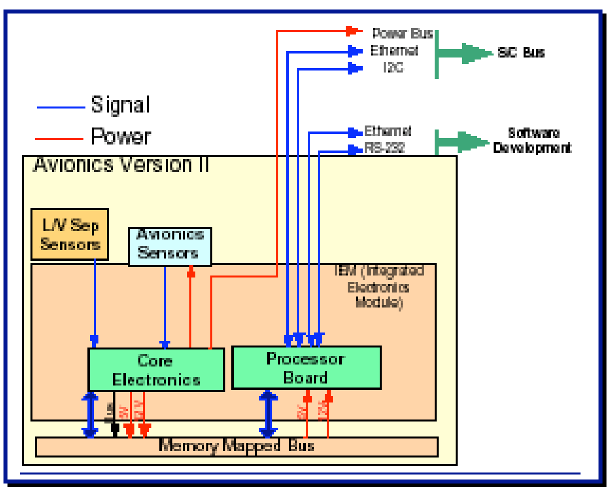

Figure 6: SCOUT Avionics Block Diagram.

Core Electronics Module

The Core Electronics Block (CEB) is a small electronics board that will reside in each SCOUT module, providing the bus stack interface to sensors, actuators, and components located in the individual component modules (see Figure 7). The CEB will offer a great deal of functionality to the SCOUT module, specifically analog data collection, discrete I/O, serial interfaces, secondary power regulation and monitoring. The CEB will utilize a radiation tolerant FPGA to also manage and direct self-diagnostic investigation of the module state of health (SOH), as well as execution of periodic and exception-based built-in-tests (BIT).

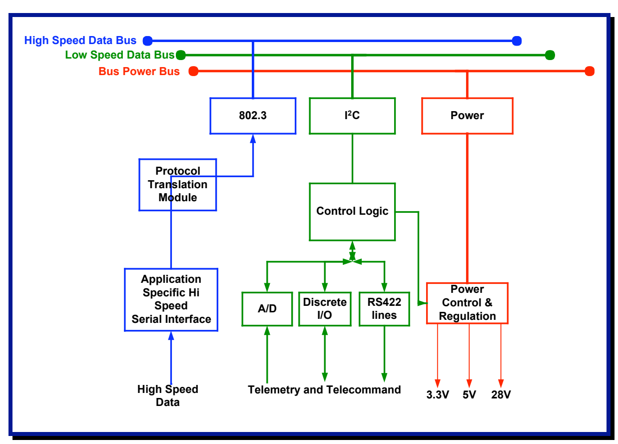

Figure 7: Core Electronics Module Block Diagram.

Lastly, the CEB is responsible for self-identification of itself to the SCOUT data bus, as well as providing a detailed report of subsystem elements hosted by the specific module, their functional specifications, and how to communicate with them.

Power Control And Telemetry Board

The Power Command and Telemetry Board (PC&T) is an integrated, single-board solution that provides the majority of the capabilities required for a simple spacecraft. A first version of this board was originally developed by AeroAstro for the NASA SPASE (Small Payload Access to Space Experiment) nanosatellite. The PC&T (Figure 8) is built around a radiation-tolerant Actel FPGA that contains firmware to issue timed commands, support communications, and command modules to switch power lines. It includes 2 MB of RAM for telemetry buffering. The FPGA provides the algorithm by which the PC&T core provides power up and reset control, command processing, launch vehicle separation switches, communications, telemetry gathering and command storage, and ground support.

On Board Flight Computer

SCOUT's single board computer is based on the Motorola MCF5307 Coldfire processor (see Figure 9). The MCF5307 is a widely used embedded processor which provides a standard memory interface bus, DRAM controller, I2C interface and serial interfaces. Memory is connected to the processor through a Memory/EDAC controller which will be custom designed into an Actel FPGA. The memory/EDAC controller will support boot ROM, Flash memory and

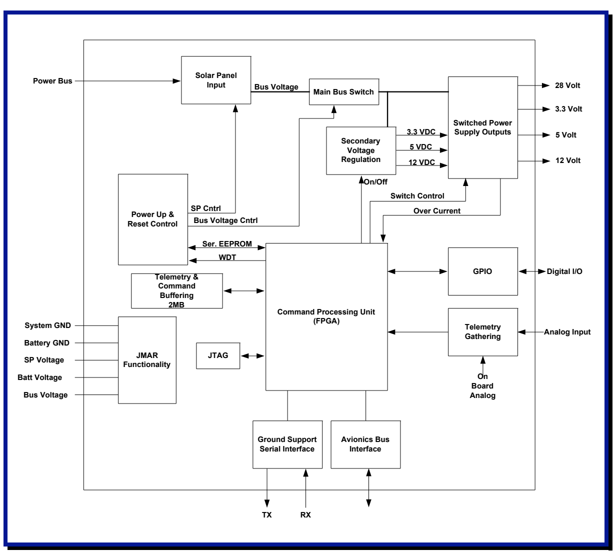

Figure 8: PC&T Block Diagram.

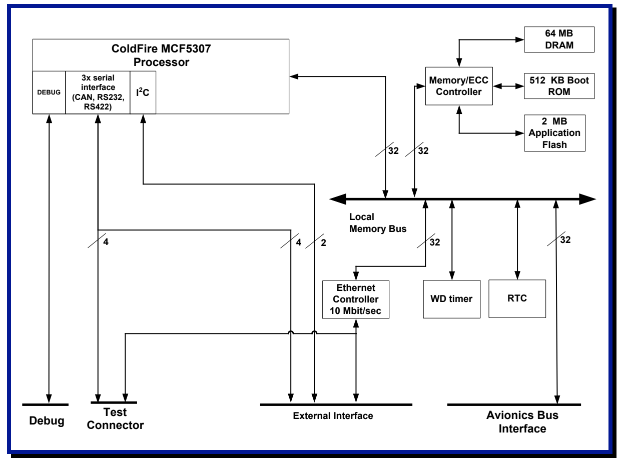

Figure 9: On Board Computer Block Diagram.

DRAM (with help from the MCF5307 DRAM controller). The local memory bus will be brought off-card to allow the processor to access peripherals on other parts of the system.

The single board computer will also provide an 802.3 (Ethernet) interface for debug and communication to other peripherals. The 802.3 interface will be based on Standard Microsystems LAN91C96 Ethernet MAC/PHY protocol. The LAN91C96 does not need a PCI bus and provides direct interfacing to the MCF5307 through the local memory bus.

The MCF5307 has two configurable UARTS. These UARTS, with the help of external logic, can be configured as an RS-232, RS-422, or CAN bus interface. These serial channels will be brought off-card to interface with other spacecraft peripherals or for testing purposes. The single board computer will provide a direct interface to the MCF5307 debug port for system testing. In addition, the MCF5307 processor's I2C bus is also brought off-card to interface with peripherals, such as analog to digital converters, digital to analog converters, and EEPROM. Other functions include power-on-reset, watchdog timers, and a real-time clock.

Software

The SCOUT flight software has been designed with flexibility in mind, with core software implemented to handle events, telemetry gathering, communications, and health and maintenance responsibilities. A simple framework has been devised that allow the operator to set the behavioral rules by which the spacecraft operates (see Figure 10). Frameworks include, but are not limited to, a Command Handling Table, Event Handling Table, Health and Maintenance Table, and a Telemetry Handling Table.

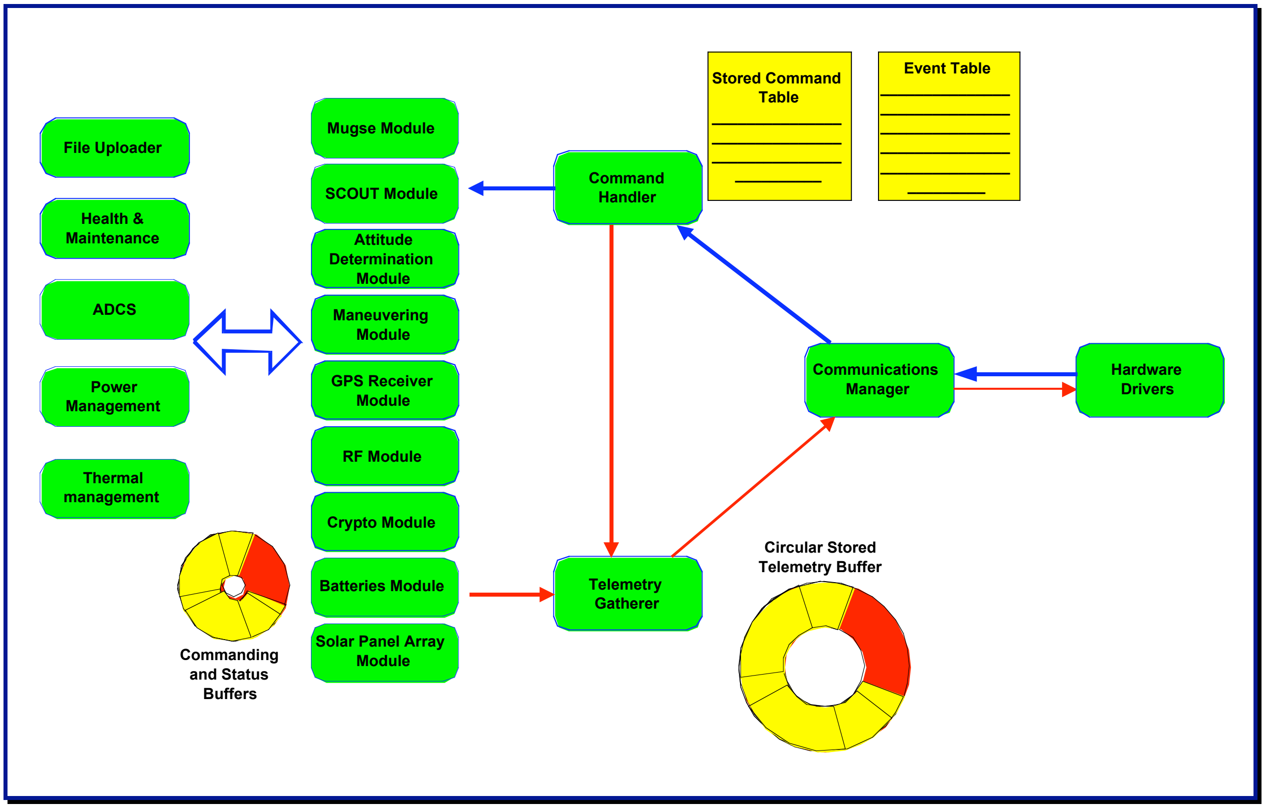

Figure 10: SCOUT Flight Software Architecture.

Each hardware module will have a corresponding software module, which the application software utilizes for commanding the module. Modules are hierarchically categorized by the function they perform and the information they provide and/or require. By organizing modules in this manner, high-level software ICDs can be defined that identify commands and data formats that functionally-similar components will recognize and share in common. Defining such an ICD that specifies the data types, functions, and parameters that these functions require ensures that swapping modules is transparent to the field integrator.

Diagnostics and Built-in-Test (BIT)

One of the tasks that each CEB must execute is to perform a series of BIT as defined by the specific design of the module. Each BIT has pass/fail criteria for every component being tested. These tests return standard diagnostics codes that would allow the field integrator to quickly and efficiently identify, isolate, and replace faulty components. Each module is capable of performing BITs as a standalone, by connecting the module directly to a piece of ground support equipment (GSE), or as an element of an integrated SCOUT vehicle stack. Built-In-Test can also be performed while in orbit. The return codes are transmitted to the ground as part of the RF stream

RF Communications

Every SCOUT-based spacecraft is expected to require a communications transponder. The modularity of the system will allow many different transponders to be developed over time at various data rates, communications bands, and modulation formats. As a starting point, it is assumed that the first-generation communications transponder will include an S-Band Uplink at data rates up to 2 kbps, an X-Band Downlink at data rates up to 750 kbps (limited by the downlink transmit power of 1.5 watts), and a 4-tone non-coherent ranging system. A block diagram of this system, which is expected to include CCSDS-compliant error correction coding on the downlink, is depicted in Figure 11.

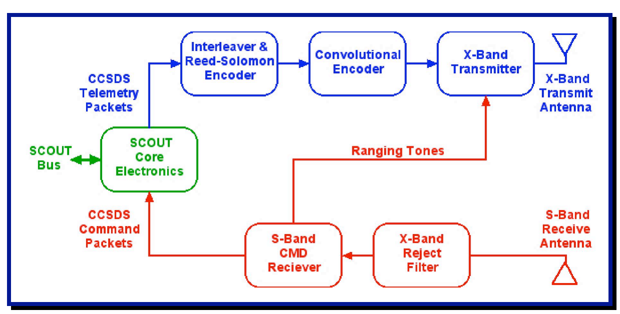

Figure 11: Transponder Block Diagram.

This design will be derived from an innovative X-Band transponder developed at AeroAstro for the NASA ST5 program. A layout shown in Figure 12 demonstrates how this existing design can be easily packaged in a 2 cm height SCOUT module. The transponder module will use separate patch antennas, custom-developed by AeroAstro in partnership with Spectrum Microwave, that are tuned to the appropriate bands for uplink and downlink communications.

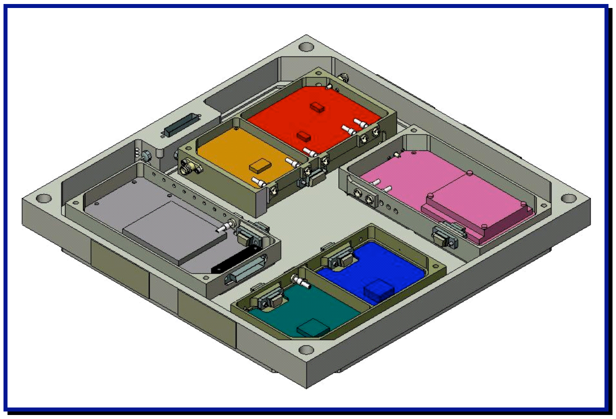

Figure 12: Transponder Module.

Attitude Determination & Control System

The ADCS module provides the control torques and command authority necessary to stabilize the SCOUT vehicle, reject disturbances, and orient the spacecraft. Depending on the specific stack configuration and mission requirements, a host of ADCS modules are available including attitude control methods and their associated options, means for determining spacecraft attitude and propagating state vectors, and available methods for orbit determination. In order to provide an ADCS solution that affords the greatest functional capability to a broad range of possible SCOUT missions, the baseline design configuration is a 3-axis stabilized platform, though spin- or passively-stabilized configurations are easily implemented should the mission requirements dictate the preference.

Attitude Determination (AD)

The SCOUT AD system must be accurate enough to sufficiently orient the vehicle in inertial space and provide regular attitude updates such that all required pointing, orbit adjust, and translational maneuvers are conducted with acceptable precision and efficiency. In addition, during activities or periods of coasting in which sensor updates are not being taken or are otherwise unavailable, the AD system must still be able to determine its state. To do so it must be capable of estimating its attitude by either propagating an analytic model of the vehicle or through Kalman filtering measured inertial rates.

Depending on the attitude knowledge requirements specified by the mission, a host of AD Module options are possible. For a robust capability, a multiple sensor design such as the one shown in Figure 13, will mitigate sensitivity to orbit selection and Sun/Earth/Moon interference within the field of view. In addition, the featured design allows for autonomous platform de-tumble and rate-nulling, as well as initial attitude acquisition from both a known geometry and in a Lost in Space (LIS) mode. This ADCS Module includes the following components:

- Four AeroAstro miniature star trackers (ST) with two image processors
- Three orthogonal MEMS Gyrochips (GC)
- Three-axis magnetometer (Mag.)
- Four AeroAstro Medium sun sensors (SS) and calibration Tables
- Module electronics, i/o and filter software, and AD algorithms
- SCOUT Core Electronics Block

Attitude Control (AC)

Based upon the preferred stabilization methodology and mission requirements, several attitude control solutions are easily implemented in the SCOUT architecture. As fine pointing (i.e. ≤ 0.1°/axis, 3□) is not a strict metric of most envisioned SCOUT missions, it was determined that a "bang-bang" control system enabled by a complementary Propulsion Module with appropriately

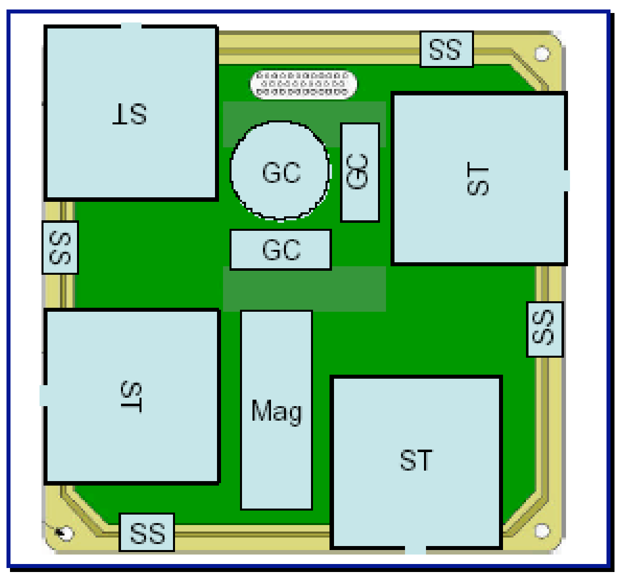

Figure 13: SCOUT Attitude Determination Module.

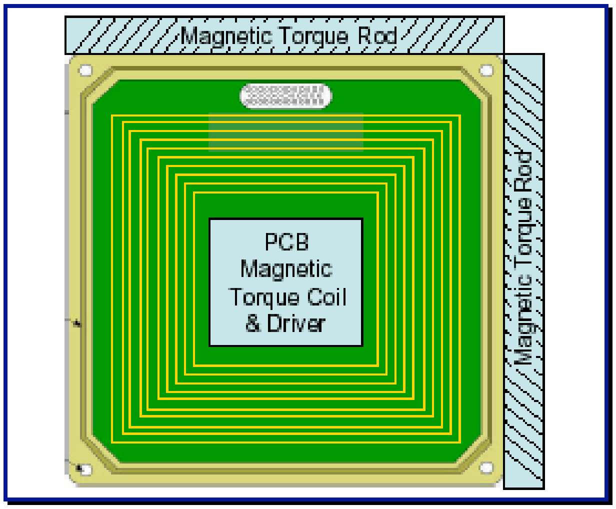

Figure 14: SCOUT Magnetic Actuation Module.

sized actuators, would best accommodate pointing, slew, and translation requirements of a 3-Axis stabilized platform. Alternatively, a three-axis magnetic control module (see Figure 14) could be included in the SCOUT stack that features magnetic torque rods located along the module sides and torque coils printed on one or more stacked PCBs. Should tighter command be needed, a micro-reaction wheel system can be implemented, where the additional torque capability for periodic momentum unloading could be supplied from either thrusters or magnetic actuation. A high-level block diagram of a SCOUT 3-Axis, "bang-bang" control system is shown in Figure 15.

Orbit Determination (OD)

To mitigate the on-board processing requirements for SCOUT, it is preferred that OD computations be conducted on the ground in conjunction with mission planning activities, with the generated ephemeris information subsequently uploaded to the spacecraft. While traditional ranging technologies can easily be employed for OD, in order to minimize the requirements to coordinate groundstation access to support rapid acquisition and high-slew tracking systems required for LEO operations, SCOUT will nominally utilize a 12-channel onboard GPS receiver developed for space applications to perform OD. The GPS Position-Velocity-Time (PVT) solution will enable a high fidelity orbit model to be established though normal telemetry downlink. In addition, because the GPS system is able to provide samples from its entire trajectory and not just a brief groundpass segment, the numerical basis for rectifying the orbital elements is greatly increased. The GPS Module features a custom Rad-Hard ASIC, all required software required for Kalman filtering PVT data and propagation of vehicle state vectors against the orbit model. The module design features antennas on all external faces and is capable of tolerating intermittent GPS signal drop-outs.

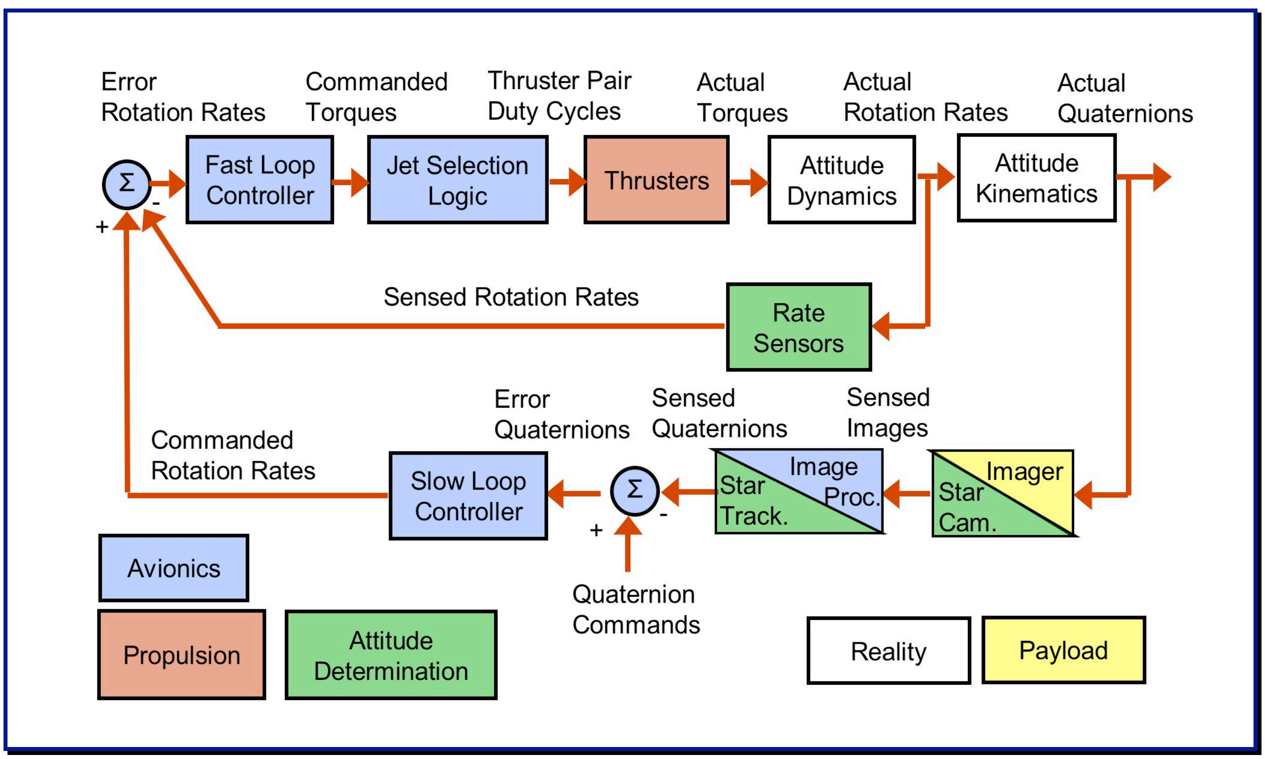

Figure 15: SCOUT 3-Axis ADCS Block Diagram.

Propulsion

As a consequence of a responsive, field-configurable architecture, it was determined that the baseline SCOUT Propulsion Module must be a non-toxic system and represent a low operational safety risk. In addition, an efficient design was also desired. Upon consideration of applicable technologies, a hot Nitrous Oxide (N_2O) decomposition thruster system was identified for its particular suitability to the SCOUT concept. Utilizing a readily available, stable, non-hazardous propellant (N_2O), it is stored as a liquid within a titanium conformal tank.

Featuring an integrated MEMS feed system of regulated micro-plenum chambers that hold isolated vapor, individual thrusters utilize a local catalytic decomposition when actuated to produce an effective I_{sp} of 120-200 seconds (see Figure 16). While a simple cold-gas system was considered, its represents a much less efficient design (I_{sp} of approximately 60 seconds) for the targeted SCOUT payload mass fraction.

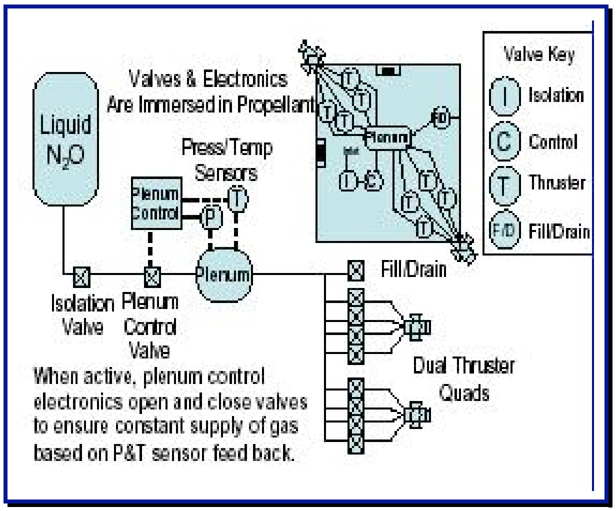

Figure 16: SCOUT Propulsion Module.

In order to effect the necessary control authority and symmetry, it was determined that the propulsion system be divided into two paired assemblies that are separated in the SCOUT stack by all but the payload module (see Figure 17b). Rather than developing two separate modules that offered an orthogonal symmetry for optimization of thruster orientation, a single Propulsion Module was designed that featured dual base-connectors that enabled the module to be rotated 90° with respect to the stack. With thrusters, valves, and electronics mounted to the bottom bulkhead of the module (see Figure 17a), the overall height is free to expand in unit increments as a function of required propellant (see Figure 18).

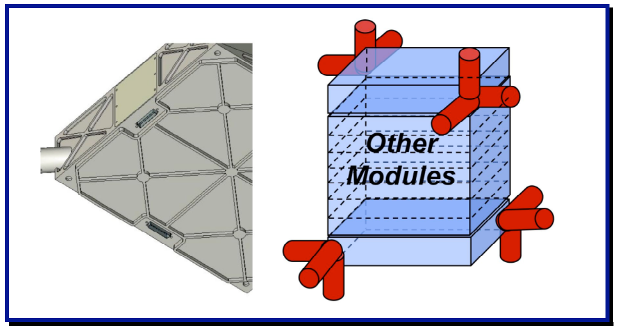

Figure 17: (a) SCOUT Propulsion Module, Underside View with Dual Bus Connectors. (b) SCOUT Propulsion Module Staking Order.

Power

For maximum flexibility, SCOUT's Direct Energy Transfer Power architecture (Figure 19) has been broken down into two modules; a Solar Panel module that also houses a shunt regulator, and the battery module(s) that houses either primary or secondary lithium batteries along with battery management electronics.

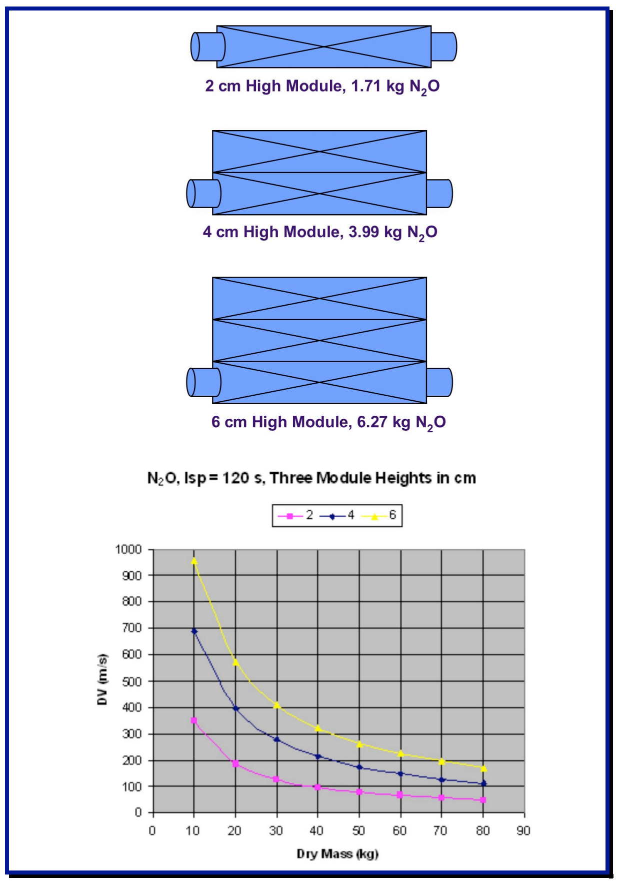

Figure 18: SCOUT Propulsion Module Sizing vs Required ΔV.

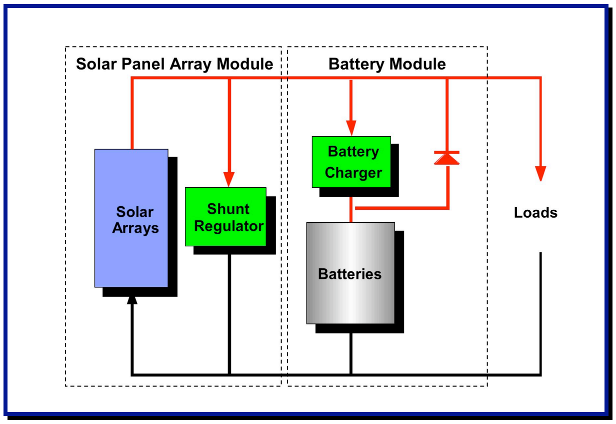

Figure 19: SCOUT Power Architecture.

The SCOUT power system is designed to handle 235W of peak power. AeroAstro has designed two different battery modules (Figure 20) for secondary Lithium-Ion batteries. One or more battery modules can be added to the stack depending on the power requirements of the specific SCOUT configuration or mission. The High Energy Battery module (Figure 20a) can house up to four independent battery strings, along with their respective battery electronics for a total capacity of 552W.hr. Each string consists of 24 standard 18650 (1.6Ah) Lithium-Ion cells in a 8s3p (8 in series by 3 in parallel) configuration. A Flat Battery Module configuration (Figure 20b) will allow us to minimize overall spacecraft volume and height on those SCOUT configurations where only one or two battery strings are required. The Flat Battery Module consists of a single string of 24 standard cells as described above.

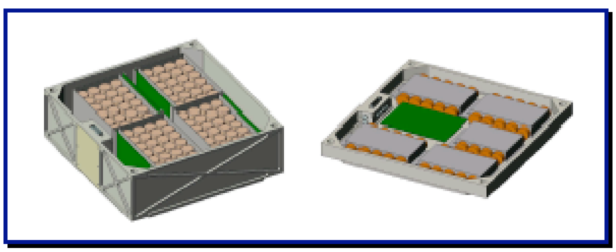

Figure 20: (a) High Energy Battery Slice. (b) Flat Battery Slice.

For the solar array module SCOUT is considering two technologies, Triple Junction GaAs (Gallium Arsenide) and Thin Film CIS (Copper Indium Diselinide). Triple Junction GaAs will give SCOUT the highest efficiency cells while the Thin Film array will offer the highest power/mass density (greater that 100W per Kg). Additionally Thin Film arrays have a great deal of mechanical flexibility, allowing AeroAstro to stow the entire array within a single standard module. Figure 21 shows the three-panel rigid cell deployment option. For

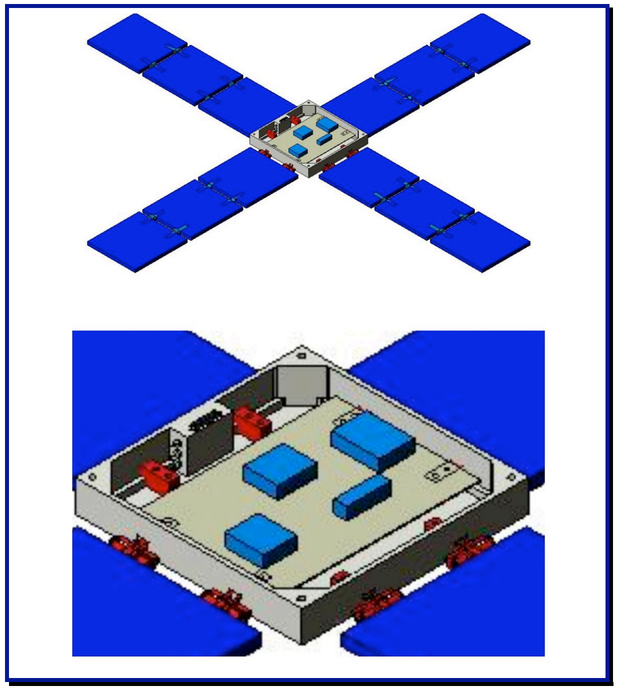

Figure 21: Solar Array Module.

a total solar cell area of array of 12300 cm2 and an average cell efficiency of 24.3% (GaAs Improved Triple Junction), the power generation capability is approximately 400 Watts with normal incidence.

Assembly, Integration and Test (AI&T)

One of the best ways to reduce the lead time and cost of deploying small satellites is to reduce the level of testing and analysis required for launch. At this time, most military satellites are designed and built to the very strict requirements of MIL STD 1540 and MIL HDBK 343. While commercial and civil missions are not subject to the same exacting standards for analyses and tests performed prior to payload launch acceptance, they still incur design and AI&T programs that average three years. In order to leverage the responsive capability afforded by the RASCAL launch system, a vastly reduced set of testing and analysis standards need to be created for the SCOUT architecture.

Fundamental to the SCOUT concept of AI&T is the implementation of open architecture standards and robust interfaces that can support a customer payload being integrated and checked out at the launch site. Upon receipt of a "build" order for a specific SCOUT vehicle, a dynamic AI&T process will commence. In much the same way a computer manufacturer does not require complicated clean-room procedures, nor rely upon custom equipment for different assemblies of components. SCOUT AI&T will only require use of a portable Master Universal Ground Support Equipment (MUGSE) to provide all process directions to technicians working in a field-deployable clean tent.

The MUGSE is equipped with an easy to use GUI, bus power supply, and connectivity to both the low- and high-speed bus. When communicating with the SCOUT vehicle (via an access port), the MUGSE will conduct all module interrogation and check-out, certify dictionaries (command and telemetry), perform overall stack functional verification, and configure all mission-specific software drivers and parameters (e.g. mass properties and PID control gains).

In addition to the intelligent, self-diagnostic built in test software that is managed by the MUGSE, the responsive nature of the SCOUT architecture is also largely predicated upon pre-qualified component modules that greatly reduces AI&T schedule. As detailed in Figure 22, all qualification and acceptance testing of component modules is conducted by the supplier. Delivery to the Field Facility represents both the vendor's certification of manufacturing and testing quality, with a commensurate acceptance of risk by the customer. At the time of deployment order execution, the required SCOUT component modules (identified by the MUGSE) are layered from "bottom-up" depending upon the mission-specific configuration, typically beginning with the payload adaptor fairing (PAF) interface module (PIM), and working up towards the payload module(s), which complete the stack.

Another important aspect of rapid deployment is the payload's ability to become operational virtually immediately upon reaching orbit. This implies that the SCOUT is active during launch, receiving time and position data from its GPS receiver and preparing to execute pre-loaded commands upon separation from RASCAL. Upon separation, the SCOUT would be able to autonomously de-tumble, acquire attitude, and perform an functional state of health (SOH) check-out of subsystems via the same BIT and diagnostic routines executed during ground AI&T. Precluding the need or desire to upload software patches or re-image the system, the SCOUT vehicle would commence normal operations and begin supplying data according to its operations plan.

Sample SCOUT Configurations

To define and envelope the scope of potential applications and missions for a SCOUT vehicle in either a single or multi-element deployment, a comprehensive investigation of candidate functions and opportunities was conducted. Based upon the results of this activity, candidate mission profiles were sub-divided into top-level categories aligned by the service function or utility to be provided and the nature of the intended role of the SCOUT vehicle(s). An overview of three sample missions are presented, with Table 4 providing a breakdown of potential SCOUT subsystem modules with cross-reference to those required for each of the discussed applications, not including payloads.

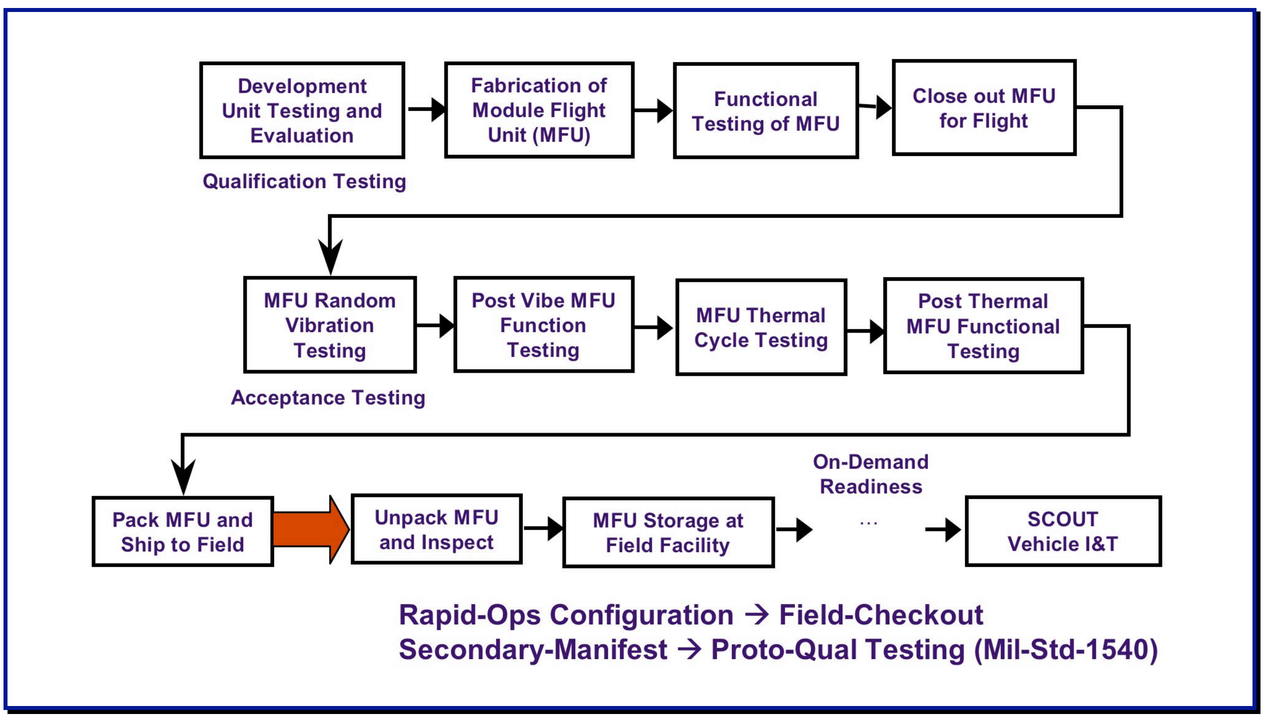

Figure 22: SCOUT AI&T Process Flow.

Table 4: SCOUT Module Matrix

Module Category	Module ID	Module Name	Escort	Tactical GPS	Tech Dem-Val
C&DH	1	FPGA Processor			Y
C&DH	2	CPU Processor	Y	Y	
C&DH	3	Solid State Data Storage	Y		Y
Communications	4	S-Band Transponder	Y		
Communications	5	X-Band Transponder			
Communications	6	INMARSAT-M Flight Modem		Y	Y
Communications	7	TDRS Flight Modem			
Communications	8	Intersatellite Transponder			
Communications	9	Ground Laser Transponder			
Communications	10	Cryptography	Y	Y	Y
GN&C	11	GPS Receiver	Y	Y	Y
GN&C	12	Attitude Determination	Y	Y	Y
GN&C	13	Magnetic Actuation		Y	
GN&C	14	Reaction Wheel Actuation		Y	
Propulsion	15	Divert			
Propulsion	16	Divert & Proximity Operations	Y		
Power	17	Battery	Y	Y	Y
Power	18	Solar Panel Array	Y	Y	Y
Launch Vehicle Interface	19	ESPA PIM	Y		Y
Launch Vehicle Interface	20	SHELS PIM			
Launch Vehicle Interface	21	RASCAL PIM		Y	
Launch Vehicle Interface	22	ASAP5 PIM			
Launch Vehicle Interface	23	Separation	Y		
Launch Vehicle Interface	24	External Structural Stiffeners			
Ground Support Equipment	25	MUGSE Base Plate	Y	Y	Y

Satellite Inspection & Near Field Situational Awareness (I&NFSA)

A SCOUT or multiple SCOUT vehicles could be utilized for inspection services of a friendly target satellite to aid in deployment activities, assessment of bus or payload performance, monitor the natural or hostile induced environment, and investigate anomalies.

Equipped with a payload sensor-suite that includes a visual camera, the AeroAstro RF Probe, and a laser rangefinder, SCOUT could enable analysis of antenna gain patterns, including primary and side-lobe topographies, as well as provide confirmation of deployments, alignments, or slewing and pointing offsets. Similarly, this capability could be applied to the investigation and resolution of on-orbit anomaly issues.

Positioned in a stable proximity orbit about a target asset, in benign conditions SCOUT would provide the capability to detect contamination generated by out gassing or propellant leaks, as well as potential threats associated with orbital debris. These functions could be extended to include surveillance and perimeter sentinel operations, in which a SCOUT could be tasked with monitoring the vicinity for the signatures of overt activities of hostile intent. In addition to increased situational awareness, SCOUT could be utilized as a flexible and steerable (i.e. range of pointing offset and slew rate) target seeker and locator. This role could enable ground operations to scan and identify desired targets of interest without having to re-task or utilize the resources of the primary asset. Table 5 includes some design specifications of a representative I&NFSA SCOUT.

Table 5: SCOUT Escort Specifications

Specification	Value
Stowed Dimensions	25cm x 25cm x 47cm
Peak Power Handling Capability	235 W
Mass	63 kg

Tactical GPS Microsatellite

A SCOUT or multiple SCOUT vehicles could be utilized in a tactical role to augment the Global Position System (GPS) network signal. Equipped with a small-scale GPS-compatible clock system or repeater payload, a SCOUT could serve as an extra node to reduce the error associated with network access, known as Geometric Dilution of Precision (GDOP), or serve to boost overall broadcast signal power, thereby enhancing the resolution of Position, Velocity, and Time solutions in support of regional, short-duration operations. From an operational perspective, access to the GPS network for navigation and orbit determination purposes, could be further extended by providing re-broadcast of system signals to space assets located at otherwise un-served orbits, such as GEO. In the advent of third-generation GPS satellites, SCOUT could provide a means of ensuring access to high accuracy navigation and position data should spectrum become constrained or precluded by the further development of the GLONASS or GALILEO networks. Table 6 includes some design specifications of a representative Tactical GPS SCOUT.

Table 6: SCOUT Tactical GPS Microsatellite Specifications

Specification	Value
Stowed Dimensions	25cm x 25cm x 45cm
Peak Power Handling Capability	235 W
Mass	75 kg

Technology Validation

The modular and configurable SCOUT architecture, in conjunction with the highly responsive deployment capability of the RASCAL system, would also enable rapid access to space for flight qualification and validation of new technologies. With a precendent to provide a high payload and power mass fraction, the specification of SCOUT modules can be configured for a specific mission and to any envelop sizing up that of the limits allowed by the launch vehicle (LV). As such, additional peak power capability can be obtained, for example, by utilizing four of the six spare bus lines for power and ground functions. Table 7 includes some design specifications of a representative Technology Demonstration SCOUT.

Table 7: SCOUT Technology Dem-Val Microsatellite Specifications

Specification	Value
Stowed Dimensions	25cm x 25cm x LV height limit cm
Peak Power Handling Capability	Up to 313 W
Mass	Up to 75 kg

Conclusions

Utilized in conjunction with the RASCAL launch vehicle, the SCOUT modular architecture will provide a heretofore non-existent capability for rapid deployment of tactical, responsive space, and time-sensitive technology demonstration microsatellite missions. Employing an open standard for development and configuration of component subsystem modules, SCOUT vehicles will be customizable to any mission-specific application, while maintaining performance- and assembly-level modularity. This standard will likewise institute a significant degree of low-level autonomy and intelligence at the module level. Leveraging this feature, ground support technicians utilizing the MUGSE will have the ability to rapidly integrate and configure any SCOUT stack: reviewing step-by-step assembly instructions, quickly diagnosing subsystem status and operational parameters, and uploading new software drivers or command dictionaries. The result, a highly capable microsatellite that can be deployed for launch within twenty-four hours of tasking.